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(54) Abstract Title
**Vibration fluid densitometer**

(57) This invention provides an apparatus for measuring the density of a liquid comprising an element which vibrates through the liquid about a rest position. The apparatus may be used to assess the natural frequency of vibration of the element in the liquid and thereby the density of the liquid. The element may be a piezoelectric bimorph.

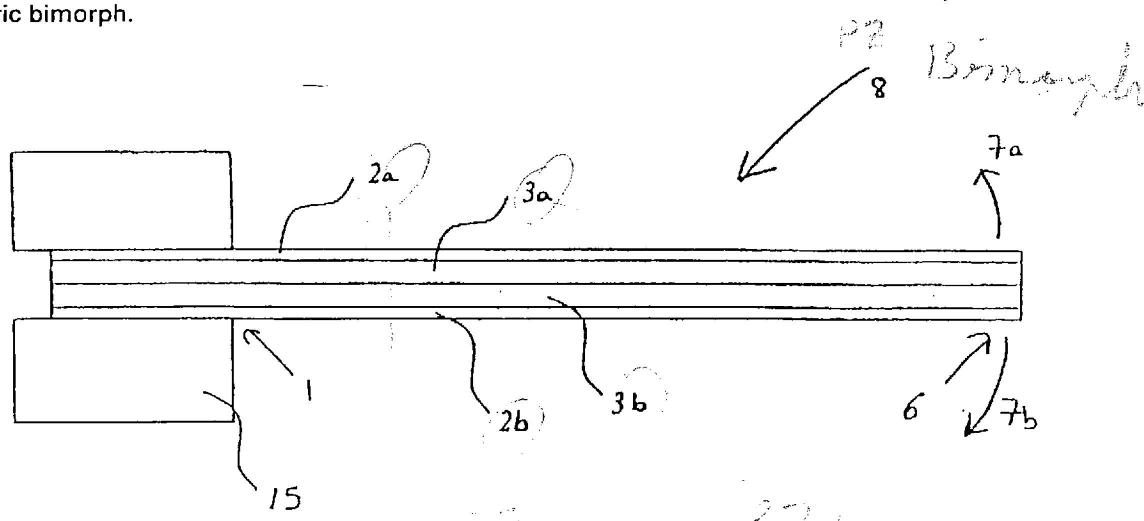


FIGURE 1

GB 2 369 887 A

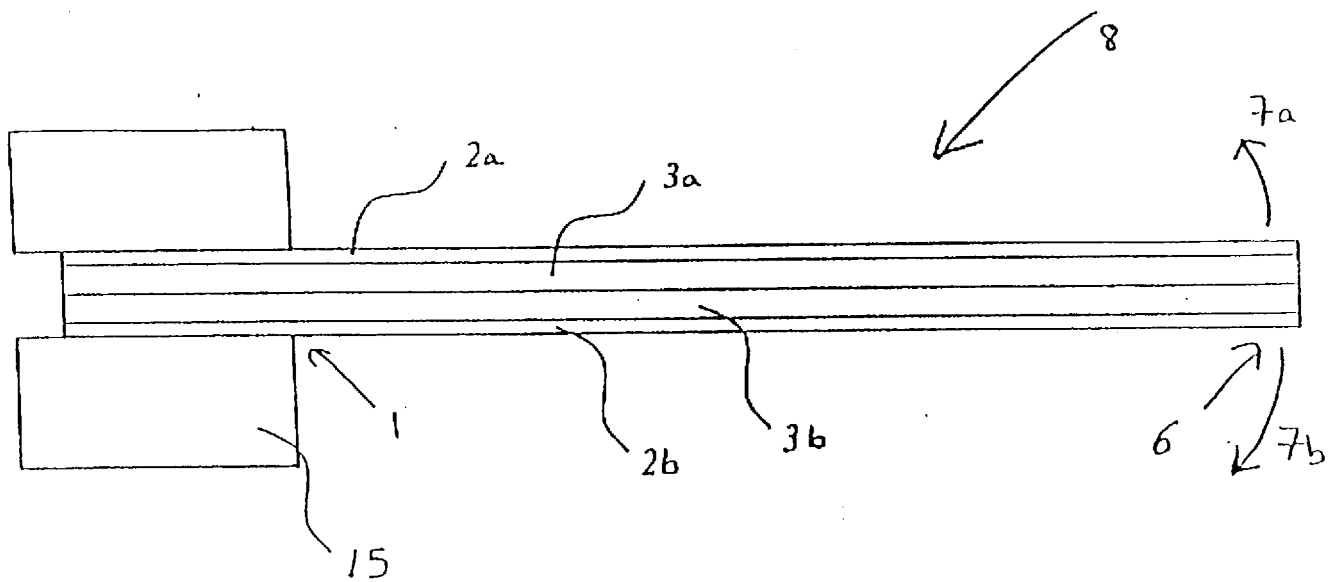


FIGURE 1

2/4

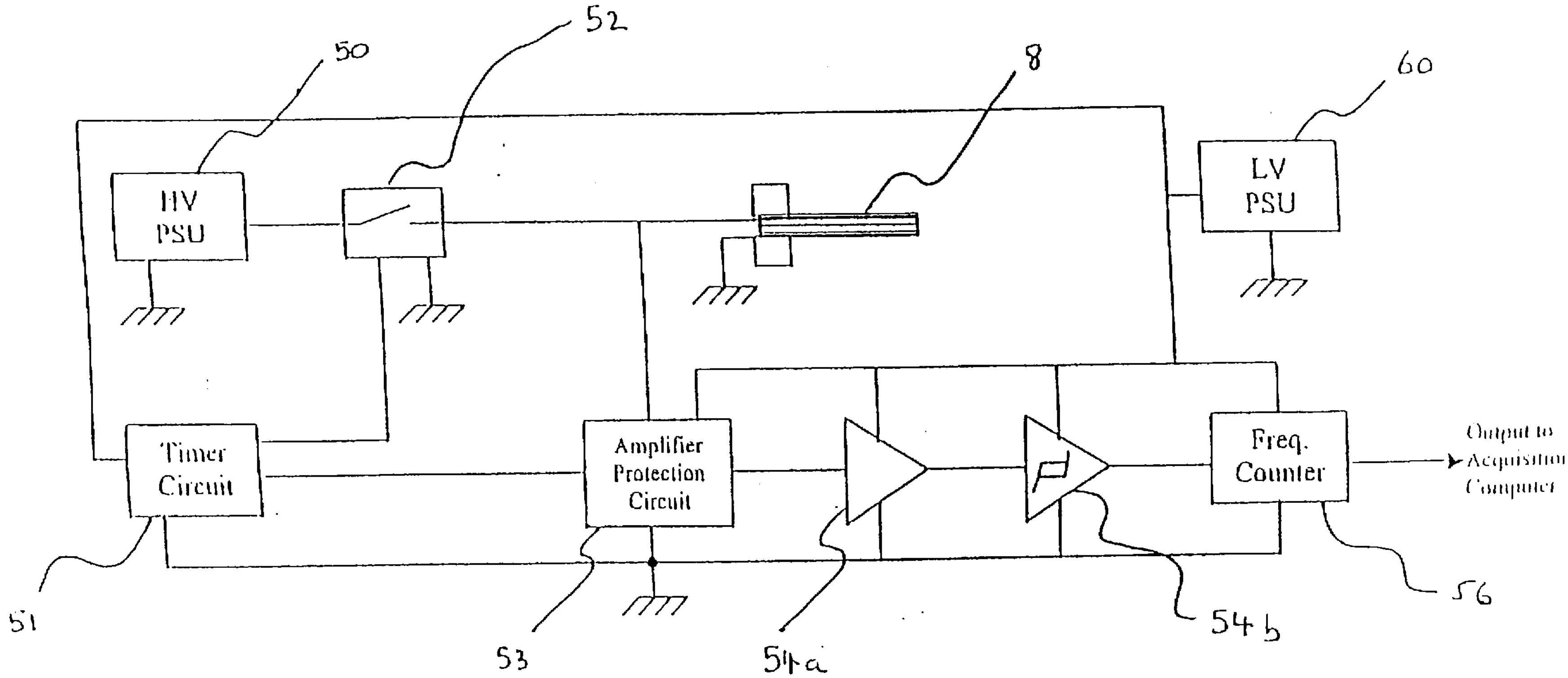
50
52
8
60
HV PSU
LV PSU
Timer Circuit
Amplifier Protection Circuit
Freq. Counter
Output to Acquisition Computer
51
53
54a
54b
56

FIGURE 2

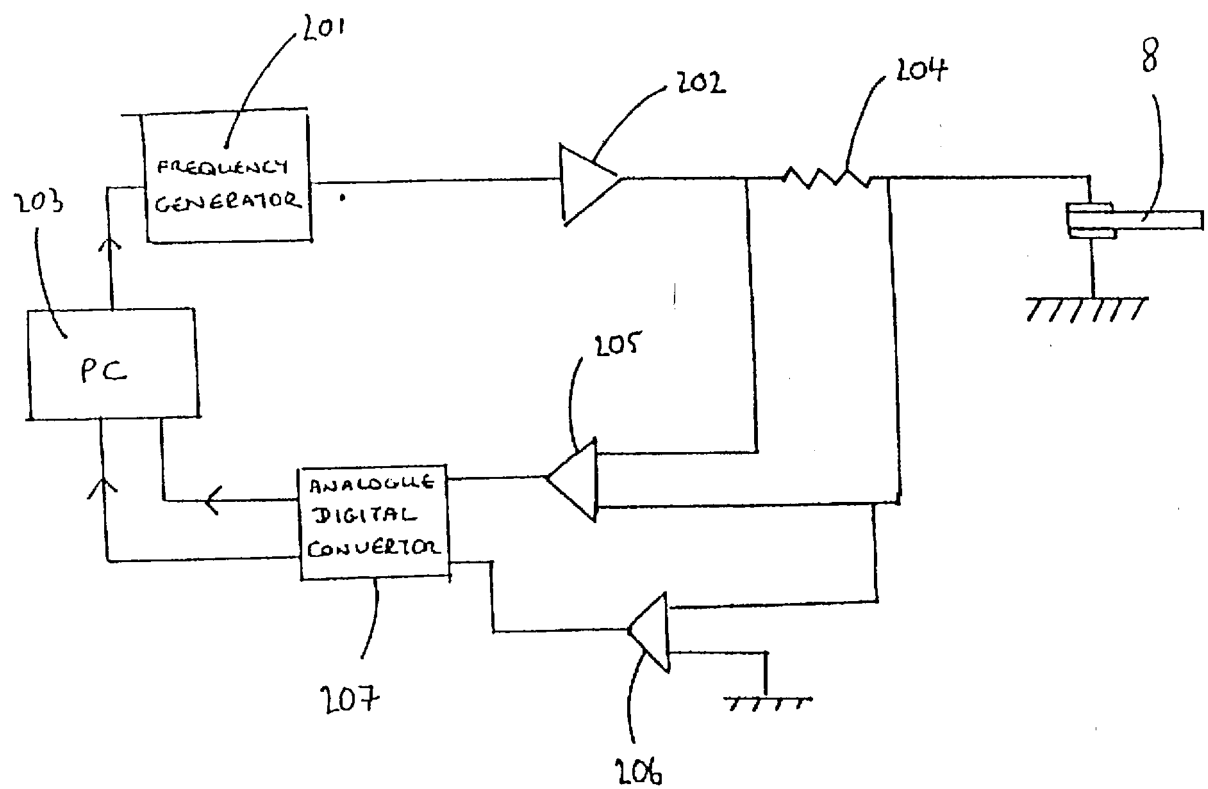
201
FREQUENCY GENERATOR
202
204
8
203
PC
205
ANALOGUE DIGITAL CONVERTOR
207
206

FIGURE 3

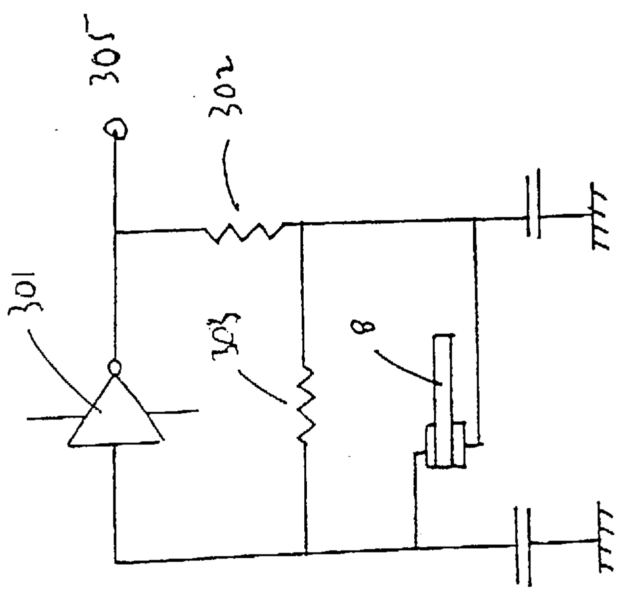


FIGURE 4

2369887



# DENSITOMETER

## Background of the Invention

The present invention relates to a method and apparatus for measuring the density of a liquid. In particular it relates to a method and apparatus for measuring the density of an emulsified mixture of liquid components.

The determination of the density of a liquid or mixture of liquids finds use in many applications. In most cases, the density of a mixture of liquids will be a different value to the density of each of the pure components. By measuring the density of a liquid mixture of known components, it is therefore often possible to find the ratio of components in the mixture. Such calculations are of use in, for example, oil production and drilling, where they might be used to calculate the ratio of oil to water at a point in a borehole. Mixtures of liquids may be homogeneous/miscible (for example water and alcohol), largely homogeneous emulsions or non-homogeneous /immiscible (for example oil and water). There is a need for a measuring device that will measure the density of all types of mixture.

European Patent Application EP 0 482 326 discloses an apparatus for measuring the density of a liquid. The application discloses a densitometer including a piezo-osillator which functions as an ultrasonic emit/receive transducer. The transducer generates two sets of ultrasonic

waves. The first is directed onto the surface of the test liquid and the second is directed onto a reference interface (in contact with ambient air); the sets of waves generate two sets of echos. The echos are received and compared by the transducer (via associated electronic circuitry) giving a value for the density of the test liquid. Effectively, EPO 482 326 determines the density of only the surface layer of the test liquid.

However, it is not satisfactory to measure the surface density when measuring the density of a mixture of liquids such as a mixture of oil and water. Even when two such incompatible liquids are thoroughly mixed, that is emulsified, one liquid will "wet" (that is, be present at) the surface more than the other. A measurement taken at the surface of such a mixture will of course measure the density of the components of the surface layer. If one liquid is wetting the surface more than the other, the composition of the surface, and thus the density measured, will be different to the composition (and density) for the overall mixture. The measurement of density will be incorrect.

There is a need for an apparatus which can measure the density of the bulk of a liquid.

It is proposed to use vibrational movement of a probe in a liquid to measure the viscosity of the liquid. The theory behind this method of measurement is that the

vibrational motion of the probe through the liquid can be treated as analagous to the motion of a pendulum. Conventional Newtonian physics can be used to calculate the friction exerted on a pendulum swinging through air; by equating friction in air to viscosity in a liquid, the rate of decay of harmonic motion of a vibrating probe through a liquid has been used to determine viscosity of liquid.

The present applicants have appreciated that such conventional calculations do not give a correct value as a vibrating probe in a liquid cannot accurately be treated as a pendulum. However, it has been appreciated by the applicants that the natural frequency of vibrational motion of a probe through a liquid is related to the density of the liquid. Furthermore it has been appreciated that this finding leads to a method and apparatus which can be used to accurately determine the bulk density of an inhomogeneous mixture of liquids.

**Summary of the Invention**

According to the present invention, there is provided apparatus for measuring the density of a liquid comprising:

paddle means which vibrates through the liquid about a rest position, the paddle means including voltage generating means located thereon, which voltage generating means generates a voltage dependent on the displacement of the paddle means from the rest position during vibration; and measuring means responsive to the voltage generated during vibration for assessing the natural frequency of

vibration of the paddle means in the liquid and thereby the density of the liquid.

If a system, after an initial disturbance, is left to vibrate on its own, the frequency with which it oscillates without external forces is its natural frequency. We have appreciated that the natural frequency of the vibrating paddle means within the liquid ("the test liquid") is directly related to the density of the liquid, and that it can thus be used to determine the density.

Preferably the paddle means includes voltage generating means in the form of a piezoelectric element. Piezoelectric elements are well known. If a piezoelectric element is displaced from a rest position it will generate a voltage dependent on the extent of displacement. Thus, inclusion of a piezoelectric element in or on or as the paddle means will cause a voltage to be generated if the paddle means is displaced from the rest position; the voltage is dependent on the extent of displacement (for example bending) of the piezoelectric element.

Preferably the paddle means includes voltage generating means in the form of a piezoelectric bimorph. The piezoelectric bimorph may be, for example, in or on or a part of the paddle means. The paddle means is preferably formed substantially wholly from a piezoelectric bimorph.

Piezoelectric bimorphs are well known. They include two piezoelectric elements oriented in opposite directions. Application of a voltage across the bimorph will cause one element to expand and the other to contract (due to the opposite orientation); the bimorph will bend. Likewise, bending the piezoelectric bimorph will cause a voltage to be generated across the piezoelectric bimorph. Thus, the voltage generated is dependent on displacement of the piezoelectric bimorph (and thus the paddle means) from a rest position.

The advantages of the paddle means including voltage generating means in the form of a piezoelectric bimorph include :

a) Increased sensitivity, because the voltage signal generated by the two piezoelectric elements that form the bimorph is greater than that generated by a single element;

b) the bimorph may be used to activate or excite the paddle means by displacing the paddle means, as described below;

c) decreased response time, because of the two piezoelectric elements; the displacement generated for a given voltage applied is effectively doubled (see below); and

d) compactness and simplicity of manufacture, because the voltage generating means and the paddle means are the same physical component.

In a first aspect of the invention the paddle means, preferably including a piezoelectric bimorph, vibrates freely through the liquid. By "freely" it is meant that the vibration of the paddle means is not driven by any drive means during the measurement operation. The paddle means may be excited initially so as to impart vibrational motion. In a preferred embodiment the paddle means includes a piezoelectric bimorph which is excited by application of a voltage across the bimorph. The paddle means is left to vibrate in the test liquid and will thus acquire the natural frequency for the paddle means/test liquid system.

In another aspect of the invention the apparatus further comprises drive means for causing the paddle means, preferably including a piezoelectric bimorph, to vibrate through the liquid about the rest position.

The drive means may drive the paddle means so it vibrates through the liquid over a range of frequencies, for example the drive means may initiate vibration at low frequency and steadily increase the frequency. Where the frequency at which the paddle means is caused to vibrate with greatest amplitude corresponds to the natural frequency increased vibration is caused due to resonance. This may be detected by the measuring means.

The drive means may be a frequency generator. The vibrating paddle will take more current from the frequency generator when it vibrates at the natural frequency. This

can be detected and used to assess the natural frequency.

The drive means may drive the paddle means so it vibrates through the liquid so that vibration will stabilise at the natural frequency. For example, the paddle may be used as the feedback loop in a self sustaining oscillator. The output frequency of the oscillator circuit will lock at the natural frequency which can be assessed to thereby determine the density.

The paddle means, preferably including a piezoelectric bimorph, has a natural frequency of vibration in any medium. When vibrating in the test liquid, the motion of the paddle means causes some of the test liquid to move with the paddle means. The movement of the paddle means is thus restricted and hindered by this liquid and the natural frequency of the vibration is altered. As noted above, the natural frequency is dependent on the density of the liquid through which the paddle means is moving. Thus, by measuring the natural frequency of vibration of the paddle means through the test liquid, or, in another embodiment, by measuring the change in natural frequency compared to that when the paddle means vibrates through a liquid of known density, the density of the test liquid may be deduced.

The components (paddle means etc.) are preferably chosen so that the natural vibrational motion of the paddle means through the test liquid (which may be a mixture of liquids) is at sufficiently high amplitude to be unaffected

by surface wetting. By "unaffected" it is meant that the compounds are chosen so that the amplitude of vibration of the paddle means is significantly larger than the thickness of the surface "wetting" layer and hence the frequency is more influenced by the bulk of the fluid mixture.

Preferably, the paddle means is shaped so that it presents a substantially concave surface to liquid through which it is being vibrated in the direction in which it is vibrating. The concave surface may be, for example, a cup-shape or bell-shape. This serves to increase the amount of test liquid moved by the paddle means compared to that moved by a substantially flat paddle means. Where the paddle means includes a piezoelectric bimorph the bimorph may include a concave surface as, for example, an integral part of the bimorph body or as a separate portion attached thereto or thereon.

Although the apparatus and method is directed to measurement of density of a liquid, it will be recognised that it is applicable to other fluids and liquid/particulate mixtures.

It will also be appreciated that although the present description is directed towards voltage generating means and measurement of generated voltage, it is possible to measure other parameters (such as current or charge) that are caused by and proportional to frequency and amplitude of vibration. Thus, when referring to the term voltage, it should be borne

in mind that this may be taken to mean variants that include any signal that can be generated in direct relationship to the extent of deviation of the paddle means from the resting position and thus used to determine the natural frequency (or decay in amplitude of that frequency etc.) of vibration of the paddle means. All such variants are within the scope of the present invention.

**Brief description of the drawings**

Embodiments of the present invention will now be illustrated with reference to the accompanying drawings, in which :

FIGURE 1 shows a cross section of a first embodiment of a piezoelectric bimorph densitometer for measuring the density of a sample of fluid;

FIGURE 2 shows a circuit suitable for use with the bimorph systems of Figure 1;

FIGURE 3 shows a circuit for use with the bimorph of Figures 1 and 2, which can be used to drive the bimorph; and

FIGURE 4 shows a further circuit that may be used as one alternative to the driving circuit of Figure 4.

**Detailed description of the preferred embodiments**

In the first embodiment, a densitometer includes an elongate rectangular measuring paddle 8. A cross section taken along the length of the paddle 8 is shown in Figure 1.

The elongate rectangular measuring paddle 8 is a piezoelectric bimorph. Piezoelectric bimorphs are well known. The paddle 8 includes two elongate rectangular elements 3a, 3b made of piezoelectric material. Each element 3a, 3b has a top and bottom rectangular face; elements 3a and 3b are placed in contact and in register so that the top face of element 3b is completely covered by the bottom face of element 3a. The free face of each element 3a, 3b (i.e. the face that is not in contact with the other element) is contacted with rectangular conductive foils 2a, 2b of the same dimensions as the faces of elements 3a, 3b. The bottom of conductive foil 2a is in contact with the top face of element 3a and the top face of conductive foil 2b is in contact with the bottom face of element 3b. The measuring paddle thus resembles an elongate rectangular sandwich having four layers; in ascending order (i.e. from the bottom layer up) these layers are: layer of foil 2b; element 3b; element 3a and foil 2a.

One end of the elongate rectangular measuring paddle 8 is fixed in clamp 15, which is located in a housing (not shown). At the clamped end 1, the conductive foils 2a, 2b are attached to electrical connections (also not shown).

The end 6 of the measuring paddle remote from the clamped end 1 is free to vibrate. The elongate rectangular measuring paddle 8 and housing is enclosed in a protective coating (not shown). The coating may be of conventional plastic material, but the material is chosen so that the sleeve is flexible thus allowing the measuring paddle 8 to vibrate. Examples of suitable coating materials are sprayed Teflon, polyamide etc.

Figure 2 shows an example circuit suitable for use with the embodiment of Figure 1 that can alternately excite and then monitor the measuring paddle 8, which is a piezoelectric bimorph. The circuit is easily assembled from common components and lends itself to microprocessor control if the user wishes.

A high voltage (40 - 200 V)power supply unit 50 is connected to the measuring paddle 8 via solid state switch 52. The power required is determined by the characteristics of the measuring paddle 8.

Solid state switch 52 is connected to a timer circuit 51. The timer circuit 51 is supplied by and connected to a low voltage power supply unit 60, which also provides power for an amplifier protection circuit 53, frequency counter 56, and amplification components in the form of amplifier 54a and Schmitt Trigger 54b. The timer circuit 51 and switch 52 are arranged so that the amplifier 54a, 54b and

the frequency counter are activated at the same time as the high voltage power supply 50 is switched off.

The circuit is also arranged so that output voltage signal from the measuring paddle is supplied to the amplifier protection circuit, amplified by amplifier 54a, filtered by Schmitt trigger 5b, and then fed to the frequency counter. The output from the frequency counter 56 is monitored and analysed by a computer and associated software which is arranged to calculate, from the natural frequency of vibration, the density etc. as discussed below. In one alternative, the output may be displayed on an oscilloscope.

The operation of the densitometer is now described. In Figure 1, the measuring paddle is in a rest position in which elements 3a, 3b are both straight. The measuring paddle 8 is resiliently flexible in the plane of the rectangular layers 2a, 3a, 2b, 3b, and can thus be displaced from the rest position, for example by exerting an upward or downward force on free end 6 (e.g. in direction 7a or 7b). If the force is removed, the measuring paddle 8 will attempt to return to the rest position. In returning to the rest position, the measuring paddle 8 will pass through the rest position and bend in the opposite direction; bending and releasing the measuring paddle 8 causes vibration or oscillation about the rest position.

The sandwich structure of conductive foils 2a, 2b and elements 3a, 3b of piezoelectric material described above means that the measuring paddle functions as a piezoelectric bimorph. Therefore, the measuring paddle 8 can be displaced from the resting position by applying a voltage (the "initiating voltage") which may be up to several hundred Volts. The measuring/activation circuitry is shown in Fig 2 and is described above.

The timer circuit 51 closes switch 52 connecting the high voltage power supply unit 50 to the measuring paddle 8 for a fraction of a second. The voltage from the power supply unit 50 is applied across the elements 3a, 3b via the conductive foils 2a, 2b and connections. The orientation of the piezoelectric material making up elements 3a, 3b is such that application of the initiating voltage causes one element, say 3a, to contract and the other, say 3b, to expand; the voltage causes the measuring paddle 8 to bend. This activation of piezoelectric bimorphs is well known and is similar to the bending action of a bimetallic strip when heat is applied. The exact duration depends on the size of the piezoelectric bimorph/measuring paddle 8 employed, the measuring paddle 8 must be excited long enough for it to bend to its maximum deflection. At this point the sensitive amplifier circuits are protected from the high voltage by Amplifier Protection Circuit 53. The Amplifier Protection Circuit consists of a barrier to voltages much above the typical response voltage of the bimorph (say 1V).

After the measuring paddle 8 has been energised the timer circuit 51 switches out the power supply 50. When the initiating voltage is removed, the expanding and contracting forces exerted by elements 3a, 3b are removed. The measuring paddle 8 attempts to return to its neutral position, vibrating as it does so (as discussed above). At the same time as switching out the supply 50, the timer circuit turns on the amplifier 54a and filter 54b and resets the frequency counter 56. As the measuring paddle 8 vibrates, the bending of the piezoelectric material which makes up elements 3a, 3b induces a voltage across conductive foils 2a, 2b. The voltage induced at a given time is dependent on the extent that the measuring paddle is displaced from the rest position at that time. The voltage caused by the vibration of the bimorph is small and passes through the Amplifier Protection Circuit 53 to the amplifier stage 54a, 54b. It is first amplified 54a and then cleaned by a Schmitt trigger filter 54b to produce a square wave that is passed straight into the awaiting frequency counter 56. The frequency counter is set to use a minimum number of wavelengths, sufficient to get an accurate reading, but not so many as to be confused by noise in the later arrivals that are highly attenuated as the vibration decay. The output from the frequency counter may simply be displayed on an oscilloscope, for example, or passed to a PC or data logging unit.

After a set amount of time the timer circuit 51 starts the sequence again.

In use, the measuring paddle 8 element is immersed in the test liquid. An activating voltage is applied, as described above, and then removed; the measuring paddle 8 starts to vibrate through the test liquid.

As the measuring paddle vibrates through the liquid in which it is immersed it sets up a vibrational system. The system will quickly stabilise so that the measuring paddle vibrates at a frequency which is the natural frequency for the measuring paddle 8/liquid system (although the natural frequency remains constant the measuring paddle will vibrate with an exponentially decreasing amplitude of vibration).

The motion of the measuring paddle 8 induces voltages in the strip shaped elements 3a, 3b, as described above. The electrical connections on the conductive foil 2a, 2b are used to measure the induced voltage. The voltages induced are measured to work out the natural frequency of vibration of the paddle/test liquid system, and the decay in amplitude; these quantities are dependent on the density and viscosity of the fluid in which it is immersed, as shown by the following:

**Calibration (Step 1)**

A typical measuring paddle 8 i.e. a piezoelectric bimorph is first characterised in the laboratory to find the natural frequency $f$ occurring for fluids of various known densities $\rho$.

A polynomial curve is fitted to the resultant empirical data:

$$\rho = g(f)$$

$$f = g^{-1}(\rho) \text{ (inverse function)}$$

In order to avoid repeating this process for each measuring paddle 8 within a batch of bimorphs, differences may be accounted for by checking each measuring paddle 8 in a known density test fluid and calculating an offset to the $g(f)$ function.

$$\text{offset } \Delta f = g^{-1}(\rho_{\text{test fluid}}) - f_{\text{test fluid}}$$

Further measurements for each measuring paddle 8 of a batch will use the modified function, i.e. with a different offset for each individual measuring paddle:

$$\text{Density } \rho = g(f + \Delta f)$$

If higher accuracy is required then each individual measuring paddle 8 should be characterised as described above.

**Measurement (Step 2)**

If a mixture of two fluids is present then the volumetric fractions of each fluid present may be calculated by linear interpolation between known points.

A sample mixture contains two fluids of known densities $\rho_1$, $\rho_2$ respectively. The measuring paddle 8 described above is used and the measured natural frequency of the measuring paddle 8 in the sample mixture $f_{sample}$ is found.

The density of the sample mixture is given by:

$$\rho_{sample} = g(f_{sample} - \Delta f)$$

For a given sample, conservation of mass dictates that the mass of the sample $m_{sample}$ is given by:

$m_{sample} = m_1 + m_2$, where $m_1$ and $m_2$ are the masses of two fluids present.

The required volumetric fractions $a_1$, $a_2$ of each fluid having volumes $V_1$, $V_2$ respectively are given by:

$$a_1 = V_1/V_{sample}; \quad a_2 = V_2/V_{sample}.$$

As there are only two fluids present, $a_1 + a_2 = 1$. Furthermore, from the definition of density:

$\rho_{sample} = m/V$ ; $\rho_1 = m_1/V_1$, $\rho_2 = m_2/V_2$ . Accordingly:

$$\text{Volume fraction fluid 1} = a_1 = (\rho_{sample} - \rho_2)/(\rho_1 - \rho_2)$$

and Volume fraction fluid 2

$$= a_2 = 1 - a_1 = (\rho_{sample} - \rho_1)/(\rho_2 - \rho_1)$$

To acceptable tolerances, it can be said that the nominal relationship is that the frequency is directly related to density and the rate of decay is directly related to the viscosity. By recording the voltages induced in the measuring paddle 8, it is possible to monitor the frequency and rate of decay of the measuring paddle 8/test liquid system using an oscilloscope or standard microprocessor computer and electronics package. Thus, the density of the fluid mixture may be deduced as outlined above together with the fractional makeup (volume fraction) of a fluid (say oil, water) mix.

In a further embodiment (not shown) the measuring paddle is shaped so that it presents a concave surface in the form of a cup or bell shape in one or both directions of vibration. The concave surface causes the measuring paddle to displace more liquid when vibrating than would be displaced by the flat faced measuring paddle illustrated in Fig 1.

Increased liquid displacement results in a greater dependency of vibrating natural frequency and hence a greater accuracy is achievable.

In a further embodiment the measuring paddle 8 (or piezoelectric bimorph) of Figure 1 are driven using a frequency generator. Suitable circuitry is shown in Figure

3. As with the previous embodiments the measuring paddle 8 is immersed in a test solution.

Figure 3 shows a measuring paddle 8 which is a piezoelectric bimorph. A frequency generator 201 is connected to the measuring paddle 8 via an amplifier 202, which amplifies the signal from the signal generator, and resistor 204. The frequency generated by the signal generator 201 is controlled by microprocessor 203 such as a PC. Microprocessor 203 also runs the measurement circuitry, which includes differential amplifier 205 which is connected across resistor 204. The output from differential amplifier 205 is fed into an analogue/digital convertor 207, and the converted signal into the microprocessor 203. Thus, differential amplifier 205 measures the variation in current in resistor 204 (and thus measures the current "drawn" from the frequency generator 201 by measuring paddle 8). The measurement circuitry also includes amplifier 206 which is connected to measure the potential difference between measuring paddle 8 and earth. The output from amplifier 206 is fed into analogue/digital convertor 207, and the converted signal passed to microprocessor 203. Thus, amplifier 206 measures the voltage on the measuring paddle 8.

During operation, the frequency generator 201 is controlled (by the PC 203) so it drives the measuring paddle 8 to vibrate, and sweeps from a low frequency to a high frequency of vibration through a range of frequencies. At

the point where the driving frequency matches the natural frequency of the measuring paddle 8/test solution it will draw more current from the frequency generator 201. The frequency generator 201 is controlled by the PC that monitors the current/voltage - i.e. the vibrational frequency - at the measuring paddle 8; the PC receives the signals from amplifiers 205, 206 and (by conventional means) calculates a simple plot of current versus frequency which reveals a peak at the natural frequency. The natural frequency of the measuring paddle 8/test solution system is used to determine the density of the test solution as discussed above.

Figure 4 shows a further example of a "driven" embodiment made by arranging circuitry so the measuring paddle 8, which is a piezoelectric bimorph, plays the part of feedback in a self-sustaining oscillator. It will be appreciated that this is closely similar to oscillators known in crystal clocks; effectively the measuring paddle 8 (bimorph) replaces the normal quartz crystal that would be present in a crystal clock.

In Figure 4, inverting amplifier 301 is connected in series with resistors 302 and 303. Measuring paddle 8, which is a piezoelectric bimorph, is connected across resistor 303. The output frequency of inverting amplifier 301 (at point 305) is measured by conventional means, for example an oscilloscope or frequency counter connected to a PC.

The output frequency of the circuit "locks" around the natural frequency of the measuring paddle 8/test solution. The natural frequency can be measured and used to assess the density as described above.

As well as the circuitry shown in Figure 4 it will be appreciated that other known circuit methods, for example such the Pierce oscillator and the Colpitts oscillator, may be used.

C L A I M S :

1. An apparatus for measuring the density of a liquid comprising:

paddle means which vibrates through the liquid about a rest position, the paddle means including voltage generating means located thereon, which voltage generating means generates a voltage dependent on the displacement of the paddle means from the rest position during vibration; and measuring means responsive to the voltage generated during vibration for assessing the natural frequency of vibration of the paddle means in the liquid and thereby the density of the liquid.

2. Apparatus according to claim 1 wherein the voltage generating means is a piezoelectric element

3. Apparatus according to claim 1 or 2 wherein the voltage generating means is a piezoelectric bimorph.

4. Apparatus according to claim 3 wherein the piezoelectric bimorph is in or on or a part of the paddle means.

5. Apparatus according to claim 3 or 4 wherein the paddle means is formed substantially wholly from a piezoelectric bimorph.

6. Apparatus according to any of claims 1 to 5 in which the paddle means freely vibrates through the liquid about the rest position.

7. Apparatus according to claim 6 which further comprises means for initiating vibration of the paddle means through the liquid about the rest position.

8. Apparatus according to any of claims 1 to 5 further comprising drive means for causing the paddle means to vibrate through the liquid about the rest position.

9. Apparatus according to claim 8 wherein the drive means is a frequency generator.

10. Apparatus according to any preceding claim wherein at least a portion of the paddle means is shaped so that it presents a substantially concave surface to the liquid.

11. Apparatus according to any preceding claim including a plurality of paddle means.

12. Apparatus substantially as hereinbefore described with reference to any of Figs 1 to 4 of the drawings.

**Application No:** GB 0030044.2

**Claims searched:** 1 to 12

24

**Examiner:** Michael Powell Waters

**Date of search:** 26 July 2001

# Patents Act 1977
# Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): G1N (NAAJG, NAAJI, NADD, NADE) G1G (GPN)

Int Cl (Ed.7): G01N (9/00), G01H (13/00)

Other: Online: WPI, EPODOC, PAJ

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| X | GB 2202944 A | (SCLUMBERGER) | 1 and 2 |
| X | GB 2200211 A | (FUJI) | 1 and 2 |
| X | GB 2001761 A | (INST STRAUMANN) see column 1 lines 75 to 84 | 1 and 2 |
| X | WO 98/09139 A1 | (GENERAL ELECTRIC) | |

| | | | |
|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category. | P | Document published on or after the declared priority date but before the filing date of this invention. |
| | | E | Patent document published on or after, but with priority date earlier than, the filing date of this application. |
| & | Member of the same patent family | | |